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TECHNICAL NOTE

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THE ARCTIC METEOROLOGY PHOTO PROBE

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SUMMARY

The Arctic Meteorology Photo Probe project at Fort Churchill, Manitoba, Canada, consisted of launching two Aerobee-100 and one Aerobee-150 rockets during September and October 1960. The program objectives were:

1. To obtain high-altitude photographs of a vigorous synoptic weather situation which would include a variety of cloud formations and also sufficient landmarks to provide ground-control reference points for photogrammetric data reduction;

2. To evaluate three types of special film for use in high-altitude rocket photography;

3. To evaluate payload and recovery techniques for future application to a family of photo probes that could be used to support the Tiros and Nimbus weather satellites.

High-resolution pictures of a vigorous low-pressure disturbance obtained from altitudes up to 140 miles have provided meteorologists a basis for studying cloud brightness and also established the value of using similar pictures, taken of an area seen by a weather satellite, for supplementing satellite photographic data. Infrared film and a Wratten 88-A filter produced the best pictures. The camera setting was 1/500 second at f/8.0. Three payloads were launched and all three were recovered, which substantiated the adequacy of the payload design and recovery techniques.

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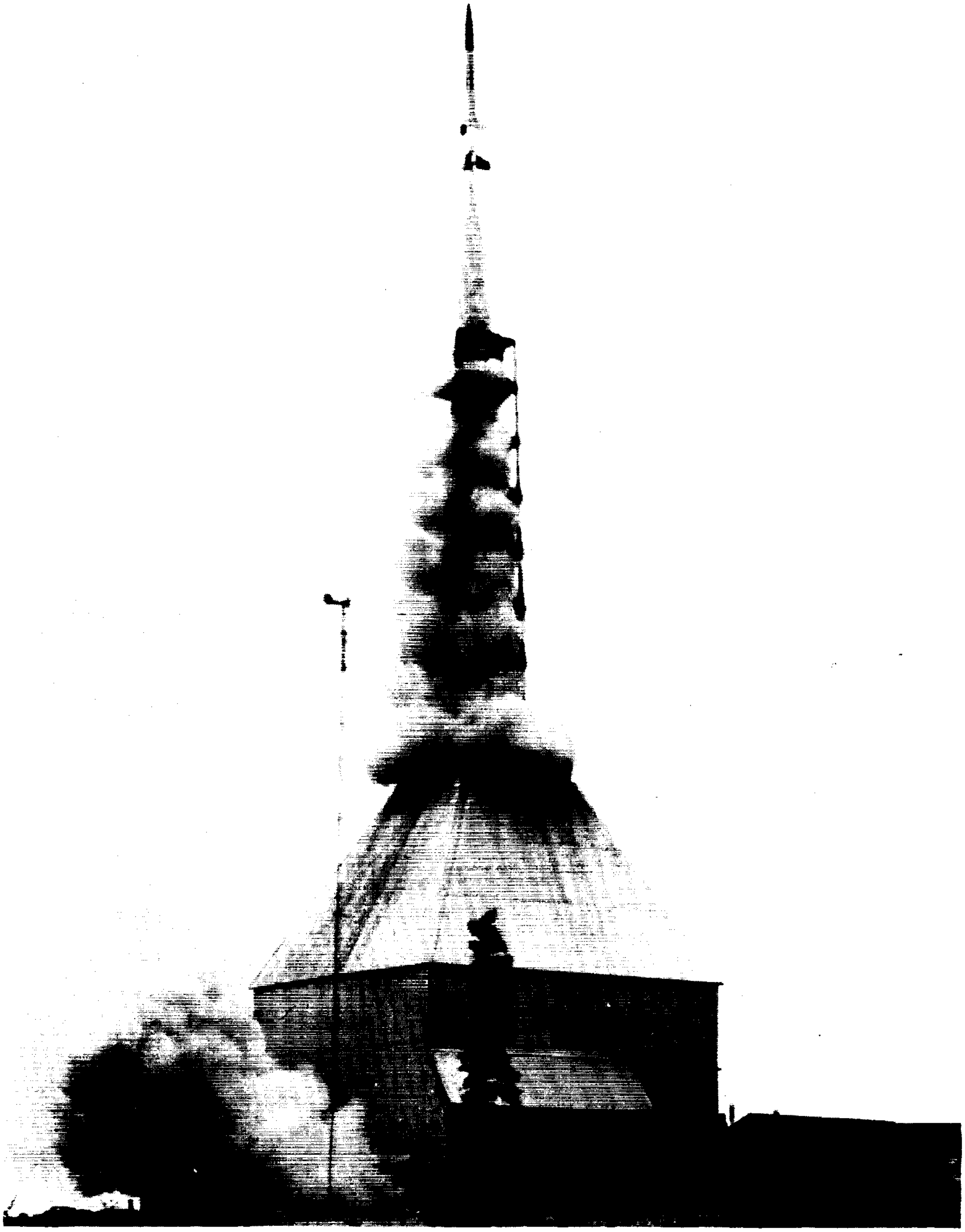

Launching of NASA Aerobee 1.03

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INTRODUCTION

During September and October, 1960, two Aerobee-100 and one Aerobee-150 rockets were launched from Fort Churchill, Canada, to altitudes ranging from 47.2 miles to 140.1 miles as a basic step in developing useful satellite and rocket probe weather interpretation techniques. The program, known as the Arctic Meteorology Photo Probe (AMPP), had a threefold purpose:

(1) To obtain high-altitude photographs of a vigorous synoptic weather situation, including both a variety of cloud formations and sufficient landmarks to provide ground-control reference points for photogrammetric data reduction;

(2) To evaluate three types of special film for use in high-altitude rocket photography;

(3) To evaluate payload and recovery techniques for a family of photo probes that could be used in conjunction with the Tiros and Nimbus weather satellites.

All three of these program objectives were realized.

Valuable program precedents were derived from earlier high-altitude missions with Vikings 11 (Reference 1) and 12 (Reference 2), which photographed the southwestern U. S. from altitudes ranging up to 158 miles. In accordance with the Weather Bureau's desire to augment its meager data on near-Arctic cloud cover, the decision was made to launch the three AMPP's from Fort Churchill in northern Canada.

The interpretation of satellite pictures transmitted from 450 miles altitude presents a major problem because of the relatively low resolution of the transmitted images. The general outline of the weather system is clear, but cloud over-run, height, and true shape are not always readily discernible. The photographic results from two of the three

AMPP launchings were excellent and provided some of the bases needed to develop reliable criteria for interpreting satellite data.

PROGRAM PARAMETERS

A prime requirement of the AMPP program was that pictures be obtained from altitudes of approximately 50 miles or more. Cloud cover photographs, insofar as possible, had to include the horizon; and further, most of the frames should be exposed as the probe passed through the peak of its trajectory. The frame rate had to be such that (1) mosaics could be compiled, and (2) the results could be analyzed stereoptically.

Further requirements were that the payload descent rate be retarded to an impact velocity of 15 feet per second, and that the film, in the event of parachute failure, be able to survive a free-fall impact on any type of terrain except solid rock. The minimum time of survival in water was to be 24 hours.

Each payload (Figure 1) was to include two cameras (for experiment redundancy and to permit evaluation of a variety of film and camera settings), programming equipment, recovery aids, tracking and telemetry electronics, and sufficient power supplies. Five payload packages were produced: one test prototype, three flight models, and one spare. Appropriate support facilities for launching, tracking, and data recovery were provided by the U. S. Army's Rocket Research Facility at Fort Churchill.

Additional requirements were that the total system be as simple as possible, commensurate with the reliability necessary for realizing the experimental goals. The engineering development had to be sufficient to establish design verification. The criteria influencing the design were: mission; rocket-created environment (acceleration, vibration, aerodynamic heating, etc.); and the ambient environment of the trajectory and impact point.

LAUNCHING VEHICLES

The launching vehicles for the AMPP were the Aerobee-100 (Figure 2) and the Aerobee-150, which differ only in the characteristics of their sustainer stages and in their altitude capabilities (Figure 3). The nose cone configurations are identical, and the payloads thus are physically interchangeable after some programmer adjustments. According to manufacturer's specifications the Aerobee-100 and Aerobee-150 can carry a 145-pound payload to altitudes of 65 and 180 miles respectively. Both vehicles are off-the-shelf items designed and manufactured originally as high altitude sounding rockets by the Aerojet-General Corporation. These are single stage, fin-stabilized, boosted vehicles. Both can be fired from the same launcher, but require different propellants for the sustainer stage.

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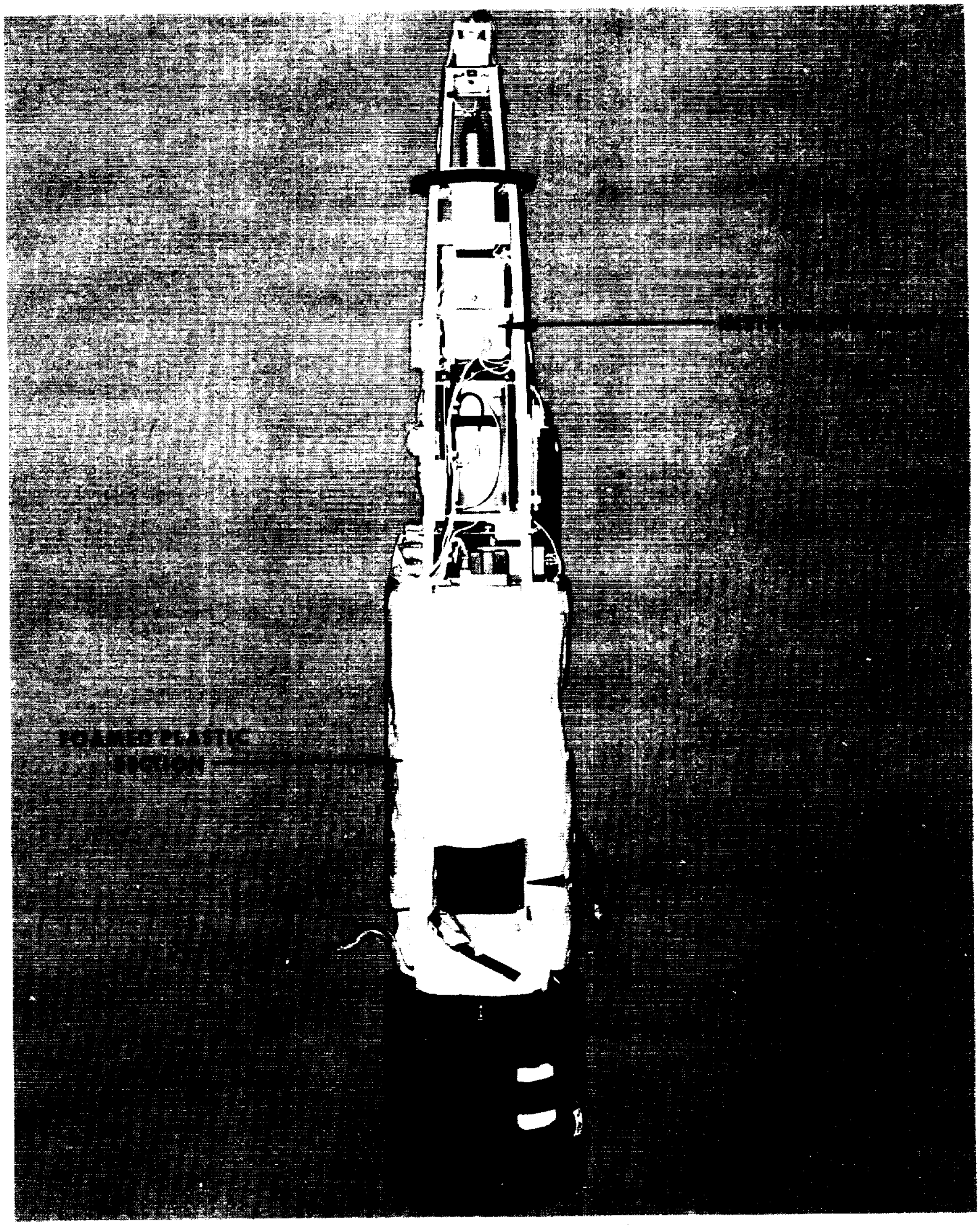

Figure 1 - Typical AMPP payload

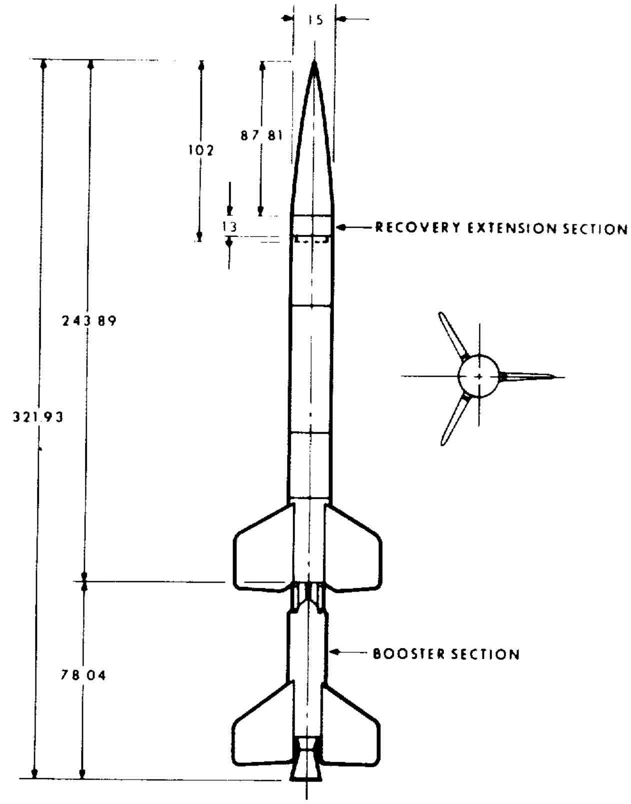

Figure 2 - Aerobee-100 rocket

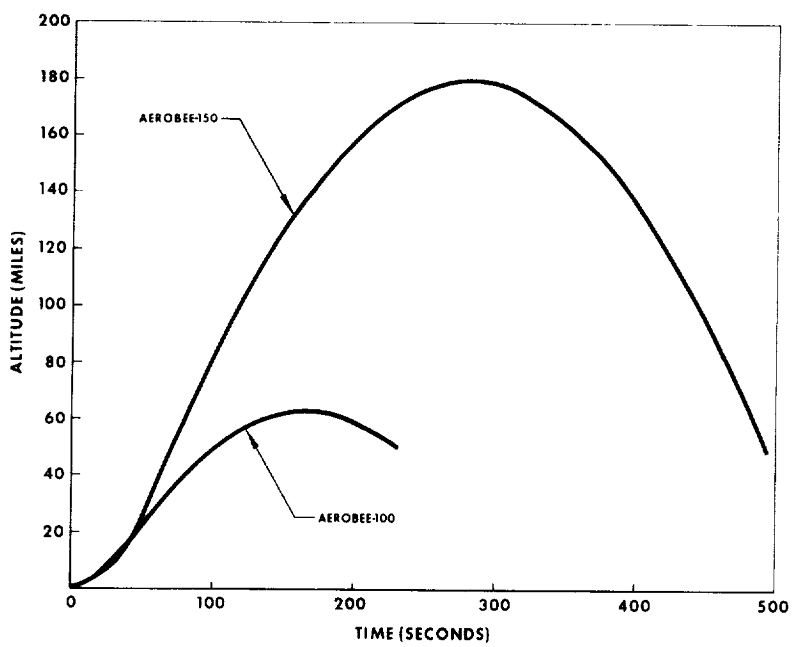

Figure 3 - Predicted altitude-time curve for Aerobee-100 and 150

PAYLOAD SPECIFICATIONS

The AMPP payload had to conform to the standard Aerobee nose cone with parachute extension attached. Ports in the nose cone permitted pressure venting as the vehicle gained altitude, as well as partial flooding of the instrument compartment in the event of water impact. The recessed camera ports were 180 degrees apart on the circumference of the nose cone. Tracking antennas projected slightly from the parachute recovery pack and constituted the only other modification to the standard profile.

Measuring from the tip of the nose cone, the design center of gravity and center of buoyancy were planned at 62-1/2 and 64-1/2 inches respectively. The total payload weight was originally estimated at 120 pounds. In practice, some component weights were in excess of the original estimates (camera pack, 8 instead of 5 pounds; parachute pack, 30 instead of 15 pounds); thus the final payload weight, including the nose cone, was 145 pounds.

The basic approach to payload structure was to make it as light as possible and still enable the cameras and film to meet free-fall impact survival requirements. The primary structure consisted of a tapered quadropod of aluminum "U" members, stabilized by sheet aluminum shelves spaced along the vertical axis to accommodate payload instrumentation.

The structural strength of the payload as a whole was specified to an ultimate safety factor of 1.25 times the limit load (with parachute operative) and a yield safety factor of 1.0 times the limit load.

PAYLOAD INSTRUMENTATION

Cameras and Films

Each AMPP carried two 70-mm Maurer model 220 aerial cameras (Figure 4) mounted approximately 180 degrees apart and aimed 30 degrees down from the "horizontal" in such a manner that, with a corrected launch attitude of approximately 90 degrees, all pictures would include the horizon. Each camera carried 50 feet of film, with a capacity of 230 2-1/4 by 2-1/4 inch frames.

Three different types of film were flown in the AMPP program. Exposure settings and filters were specified by the Eastman Kodak Company (Table 1). Variations from these recommendations were based on flight experience, as indicated in the individual flight reports.

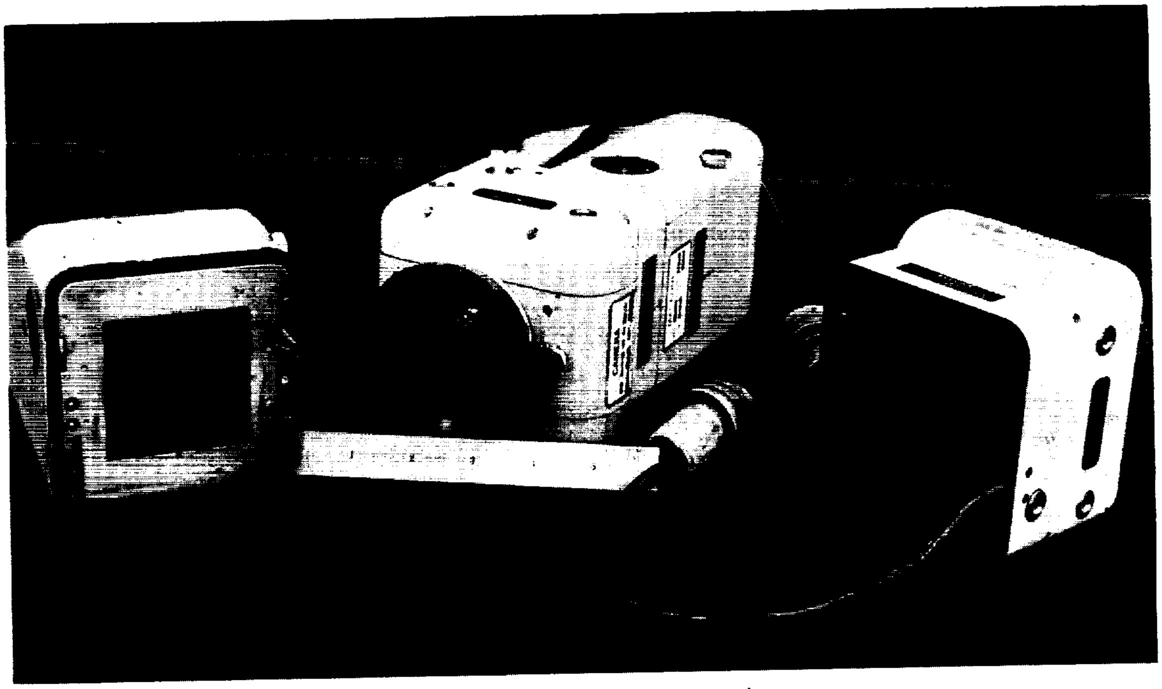

Figure 4 - Maurer model 220 70-mm aerial cameras

Table 1
Manufacturer's Specifications for Films Used in the AMPP Program

Film Type	Time	Aperture	Filter
Kodak Infrared Aerographic	1/500	f/5.6	Kodak Wratten #88A
Kodak Experimental Ektachrome Aero	1/1000	f/4.5	Kodak #8778
Kodak High-Definition Aerial Negative SO-213	1/500	f/4.5	Kodak Wratten #3

Batteries

Electric power for the entire payload was supplied by one main battery pack consisting of 20 Yardney HR-3 silver cells and two auxiliary battery packs consisting of 10 HR-3's and five HR-1's.

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Telemetry System

Each payload (Figure 5) carried a four-channel FM/FM telemeter consisting of a transmitter (227.5 Mc), subcarrier mixer, amplifier, voltage regulator, and four voltage-controlled oscillators (VCO). VCO frequencies were IRIG bands 9G, 10G, 11G, and 13G. The notch antenna was located on one of the rocket fins. Vehicle aspect and camera actuation data were telemetered.

The rocket's aspect with respect to the earth's magnetic field was determined by two flux-gate magnetometers (Figure 5). These are mounted on the forwardmost shelf of the payload and oriented 90 degrees to each other—one in line with the payload's longitudinal axis and the other parallel to the transverse axis.

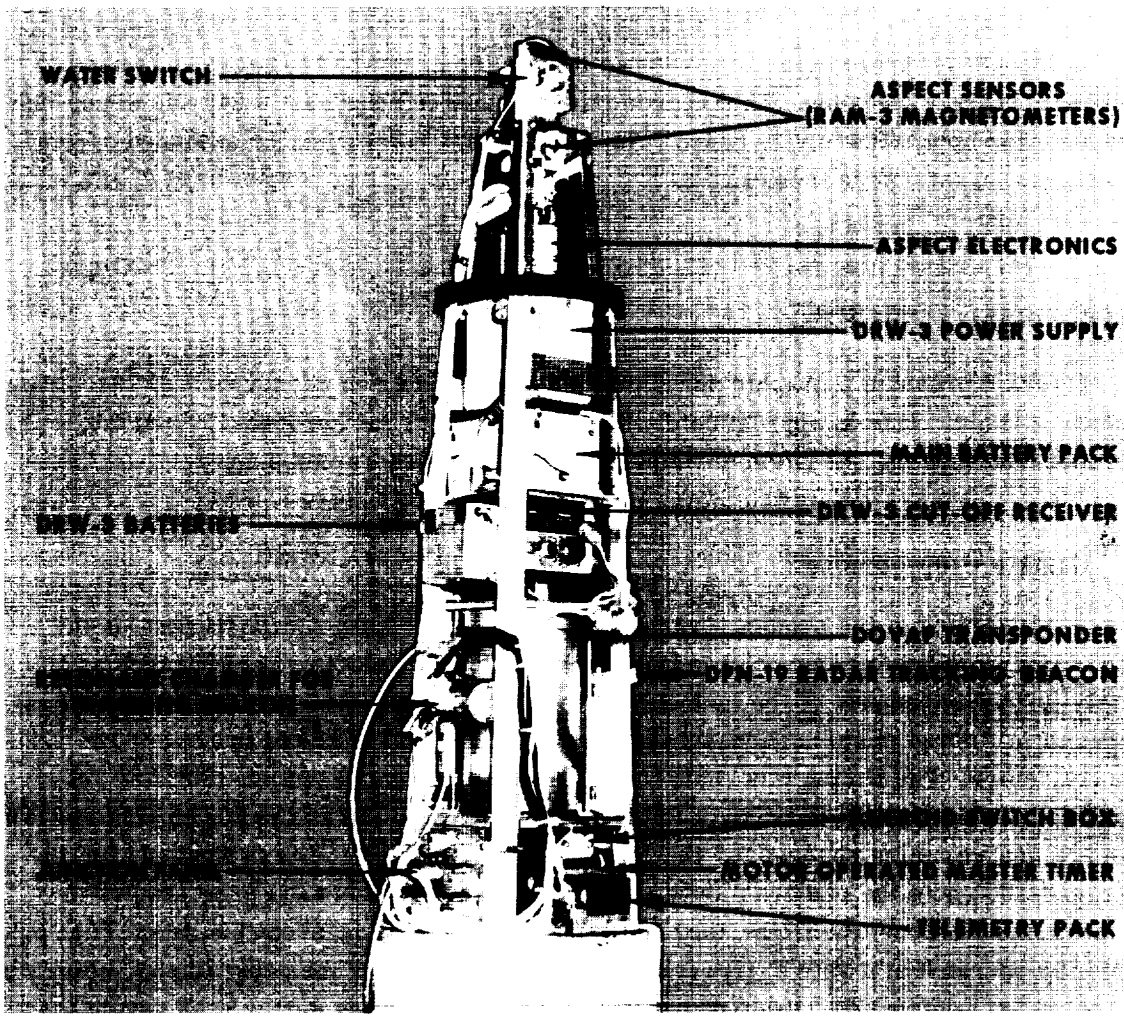

Figure 5 - Payload instrumentation

Tracking, Range Safety, and Payload Retrieval

A DOVAP T-10 transponder was included in each payload (Figure 5) to provide rocket velocity, position, and spin rate as a function of time. The DOVAP antennas were mounted on the skin of the sustainer stage.

A DPN-19 radar tracking beacon was used for range safety and payload tracking (see Figure 5). Both the beacon and the antennas were mounted in the payload to permit continuous tracking of the payload from lift-off to impact.

For range safety, a DRW-3 rocket cutoff command receiver was used in conjunction with the DPN-19. The DRW-3 was wired to a detonator block positioned to cut the fuel line in the event that range safety required flight termination.

A SARAH beacon (originally developed to help locate downed aviators) was used to facilitate payload recovery. This beacon was designed to broadcast a 243-Mc signal continuously for approximately 20 hours. As a further aid in locating the expended payload, two smoke makers were included and programmed to be activated upon impact with either water or land.

OPERATIONAL SEQUENCE

Figure 6 provides a graphic description of the sequence of events through the various phases of flight. This is approximately the same for both the Aerobee-100 and the Aerobee-150 with the exception of timer programming (see Tables 2 and 3).

Camera Programming

Actual timing of the sequence varied with each of the three AMPP flights. In the first flight (with an Aerobee-100), a failure to predict the vehicle's performance accurately (probably because of the lack of knowledge of the drag effects of camera fairings) resulted in limited mission success: camera operation was initiated too late in the vehicle trajectory. The timing was changed for the second flight (Aerobee-100), and yet again for the third flight because of the change to Aerobee-150 as the launch vehicle. The camera programming changes for the Aerobee-150 flight are shown in Table 3. In the Aerobee-100 shots the cameras, once started, ran continuously until programmed to stop. In the Aerobee-150 flight, they were programmed in five-second bursts. The cameras operated at a rate of five frames per second; and for the programmed spin rate of the rocket vehicle this resulted in the exposure of 26 frames during each revolution of the vehicle.

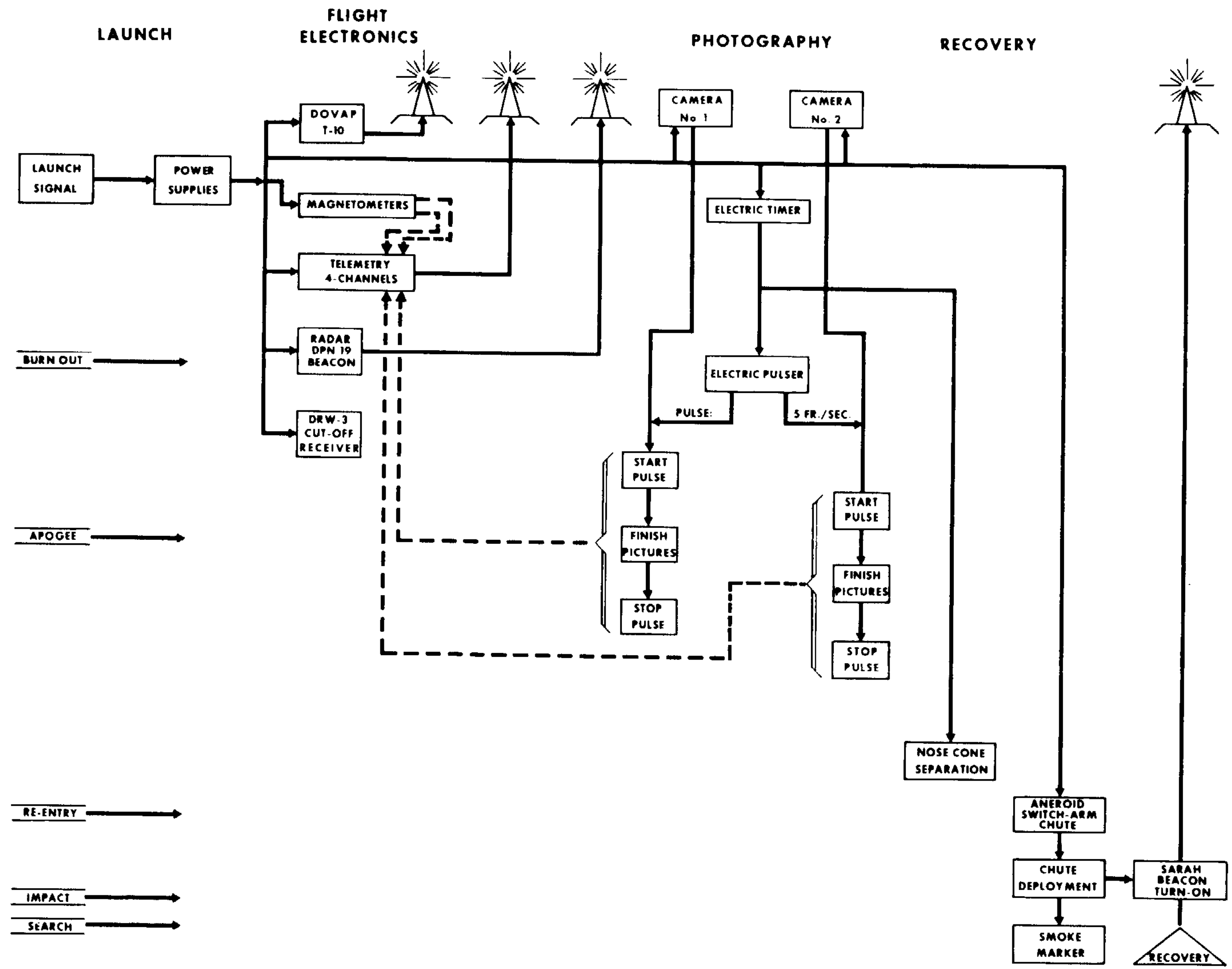

Figure 6 - Operation sequence for AMPP

Table 2
Aerobee-100 Programming for First Flight

Plus Time (seconds)	Predicted Altitude (statute miles)	Event
0	0	Booster ignition
		Sustainer ignition
2.5		Booster burnout
2.5 + Δt		Booster separation
41.0	16	Sustainer burnout
138	55	Start camera #1
153	60	Start camera #2
168	63	Apogee
198	60	Stop camera #1
213	55	Stop camera #2
233	50	Payload separation
---	(20,000 ft.)	Parachute deployment
498		Power to inertia and attitude switches.
498 + t	0	Impact; parachute release; smoke markers activated.

Master camera programming was provided by a motor-driven timer which began operation when the launch switch on the monitor panel was thrown. At a predetermined point in the trajectory (after sustainer burnout and just before apogee) the master programmer actuated another timer which pulsed Camera No. 1. After fifteen seconds of actual running time (Camera No. 1), the master programmer actuated still another timer which pulsed Camera No. 2. Each camera ran for 60 seconds – 45 seconds of actual picture taking plus 15 seconds to take care of overruns, hung film, etc. (Actually 50 feet of film was loaded into each camera, of which 5-to-8 feet was run off in prelaunch tests.)

The pulse timers, which operated the two cameras, provided a voltage signal which operated the camera motors. This information was telemetered and used as a means of time-matching the photographs with corresponding magnetometer aspect and DOVAP signals.

Table 3
Camera Programming for Aerobee-150 with Payload Separation Occurring at 490 Seconds
(Time in Seconds)

Camera 1		Camera 2	
On	Off	On	Off
105	110		
130	135		
155	160		
180	185	180	185
205	210	205	210
230	235	230	235
255	260	255	260
280	285	280	285
305	310	305	310
		330	335
		355	360
		380	385
		405	410
		430	435
		455	460

Descent

The payload was programmed to separate from the rocket during descent at approximately 260,000 feet altitude. Separation of the payload-parachute system was effected by detonating primacord that is positioned in a groove about the inside diameter at the separation joint (between the payload extension and the sustainer rocket). Separation program control was accomplished by closing Switch No. 2 on the second timer cycle (360 + 138 seconds). Separation safety was provided by means of four "H"-connected 20,000-foot-altitude aneroid switches. The power required to actuate the detonator for separation was conducted only upon successful closure of the 20K switches, i.e., these switches are in a non-operative condition at altitudes below 20,000 feet.

The backup to the program timers for accomplishing separation was provided by two parallel-connected 50,000-foot-altitude aneroid switches. These switches are non-operative at altitudes below 50,000 feet under powered flight conditions. When 50,000 feet is attained during ascent, the switches close, energizing a snap action relay and a latching relay. Both relays remain energized, but power does not flow until the switches reopen (below 50,000 feet), at which time the snap action relay opens and the latched relay remains closed. In this condition power is transferred through the latched relay, through the 20,000-foot-altitude switch bank, and to the separation detonator block.

Parachute Deployment and Impact

The parachute was programmed to deploy at 20,000 feet altitude, at which time the SARAH beacon began operating. Upon impact with land or water the parachute detached itself, smoke markers were activated, and the SARAH beacons continued transmitting. In water, the buoyancy was such that the payload would float nose down with about 20 inches showing above the surface.

TESTING

Development and acceptance testing of the AMPP payload and its various components were designed to assure that the whole payload would function properly under actual operational conditions. Essentially the tests consisted of subjecting various payload components and the system as a whole to environments simulating the whole launch, trajectory, impact and recovery sequence. All electrical, mechanical, and electronic systems were checked quantitatively and qualitatively before, during, and after each environmental sequence.

A simulated altitude of 65 miles was established in a vacuum chamber. The payload was stabilized at this pressure for one hour and then operated through a 12 minute cycle internal power. The return to sea level pressure was controlled to simulate the payload's anticipated operational descent rate. All important payload functions were monitored, including the payload separation sequence and parachute deployment.

The payload was attached to the vibration test jig in a manner which simulated the actual mounting configuration in the launching vehicle (Table 4). All critical components were operated prior, during, and after vibration test. The payload was vibrated in the vertical direction. Input was measured as close to the points of payload attachment as possible. During this test, the natural frequency of the payload was determined and recorded.

The payload was placed in a centrifuge and exposed to an acceleration of 20g in the vertical axis for 7 seconds, after which the acceleration was reduced to 12g for one

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minute. All components and circuits were checked for proper performance before, during, and after the acceleration test. Particular attention was paid to the calibration of the aneroid switches after exposure to acceleration.

LAUNCHINGS

The three AMPP flights took place on September 15, September 24, and October 5, 1960. The first two launch vehicles used were Aerobee-100's which took their payloads to just over 47 miles altitude. The third shot was with an Aerobee-150 which achieved a peak altitude of 140.1 miles.

Flight Number One – NASA Flight 1.03

The launching vehicle for the standard AMPP payload, an Aerobee-100, was fired at 1209 CST on September 15, 1960. All major system components functioned as programmed. The observed (DOVAP) peak altitude of 47.3 miles occurred at 148 seconds as compared to the predicted 51 miles at 158 seconds.

The two cameras carried Kodak Experimental Ektachrome Aero (color positive) and Kodak High-Definition Aerial Negative SO-213 (black-and-white) film. The camera settings and filters were as specified by the manufacturer with the exception that the lens opening for the color film was f/5.6 instead of f/4.5 (see Table 1). The film in both cameras ran through the magazines; the aspect data were recorded; and the parachute cutter release mechanism functioned.

Table 4
Vibration Test Data for AMPP Payload

Limits in the axial direction (Z-Z axis)	
Frequency range	20 to 2,000 cps
Spectral density	0.05 g^2/cps
Duration	1 minute
Maximum double amplitude	0.4" (0.05 g^2/cps; 10 g-rms)
Limits in the transverse direction (X-X axis)	
Frequency range	10-250 cps
Accleration	2.1 g-rms
Duration	1.5 seconds

No radar tracking data were obtained. Both plotting broads were inoperative, and the DPN-19 beacon faded out at T + 10 seconds. One telemetry channel (that for the 3900 cps magnetometer) malfunctioned, but began operating in time to signal the important phase of the trajectory. The primacord separation mechanism tore loose a major portion of the recovery-pack extension skirt. However, virtually all payload instrumentation was recovered intact and in good working order (Figure 7). There was no problem in locating the impacted payload.

The photographic results left much to be desired, since the payload did not reach its predicted altitude and the cameras began operation, at rather than before, the peak of the trajectory. Only meager information was obtained.

The camera settings for the color film resulted in overexposure. The color film did not provide sufficient contrast or satisfactory resolution of fine gradations in shading (Figure 8). Similarly, the black-and-white film did not produce the desired detail (Figure 9). However, the flight showed that all basic system components would operate as planned.

Flight Number Two—NASA Flight 1.05

The launching vehicle for the standard AMPP payload was again an Aerobee-100, fired at 1213 CST on September 24, 1960. Generally speaking, all major systems operated properly, but the one exception—loss of the parachute at an altitude of 9,000 feet—resulted in the catastrophic impact of the payload.

The landing in about one foot of water (Figure 10) effectively destroyed the payload. Both camera cases leaked and both rolls of film (infrared and black-and-white) were wetted with saline water. The films were immediately rinsed in distilled water and hand-carried, in a wetted condition, to Rochester, New York, for processing. Only a few very poor quality frames of the infrared film were recovered since most of the emulsion left the backing. Approximately 40 frames of black-and-white film were recovered — condition and quality poor. It was later determined that better results would have been obtained if the film had not been washed and had been shipped wet to the processor.

Flight Number Three—NASA Flight 4.43

The launching vehicle for the standard AMPP payload was an Aerobee-150 fired at 1352 CST on October 5, 1960. The lens aperture for the infrared film was changed to f/8.0, and that for the SO-213 film to f/5.6 (see Table 1).

All major system components functioned as programmed. All film ran through the magazines. All DOVAP stations operated satisfactorily. Radar skin track was lost eight seconds after lift-off. Radar then went to the predicted space point for parachute deployment and picked up the payload prior to ground impact. In this shot the parachute release mechanism was made inoperative in order to preclude the loss of parachute that occurred in Flight Number Two. This change proved to be a minor benefit.

The payload impacted in an area not readily accessible on foot; the down-wash of the recovery helicopter's rotors was utilized to fill the parachute and drag the payload to more accessible terrain (Figure 11). In addition to the standard AMPP payload, this shot also carried a vibration test unit included at the request of the U. S. Naval Research Laboratory.

The entire payload was recovered intact with the minor exception that the heat of re-entry from the Aerobee-150 altitude burned off the paint on the air pressure vents (or water inlets).

The cameras — programmed to shoot in five-second bursts (see Table 3) — performed as planned. Excellent photographs were obtained with both infrared and black-and-white film, including many during the optimum (peak) trajectory phase.

RESULTS

With the flight (NASA Flight 4.43) all program objectives were achieved. Numerous excellent pictures of a "vigorous synoptic weather condition" were obtained, including sufficient clear landmarks for ready reference by photogrammetric analysts (Figures 12 through 20). Two kinds of film (infrared and black and white) were evaluated with positive results. Results obtained with the color film are inconclusive. A system suitable for high-altitude sounding rocket support of the Tiros/Nimbus weather satellite program was effectively demonstrated. The U. S. Weather Bureau has since confirmed that the AMPP photographs have provided a valuable basis for the interpretation of satellite pictures.

CONCLUSIONS AND RECOMMENDATIONS

Infrared film produces the most useful high-altitude photographic results. The merits of color film were not clearly established due to overexposure. Black and white film (Figures 12, 14, and 19) does not provide as much detail as infrared film (Figures 13, 15, 16, 17, 18) and gives inferior cloud definition.

Smoke markers are not necessary to payload recovery; in fact those used in the AMPP program, for the most part, either did not operate or were unobservable.

Efforts should be made either to find cameras with better shutter life and reliability, or to design special shutters. Those employed in the AMPP cameras demonstrated a limited useful life and reliability and, probably, only careful ground checkout precluded serious inflight failure.

In the future, film which is damaged on impact should not be tampered with in any manner prior to processing; and processing should, if possible, take place at the site of launching as soon as possible after recovery.

Any further rocket firings should be conducted with infrared film in order to develop reliable criteria for filters and camera settings under a wide range of conditions. A special effort should be made to determine the usefulness of a polaroid filter in distinguishing clouds from snow, cloud height, overrun, etc.

If the program is continued, future firings of this nature should be timed to coincide with the active transit over the firing area of weather satellites, such as Tiros, for direct comparisons between sounding rocket photographs and those acquired from the much higher altitudes.

ACKNOWLEDGMENTS

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2. Baumann, R. C. and Winkler, L., "Photography from the Viking 12 Rocket at Altitudes Ranging up to 143.5 Miles," U. S. Naval Research Laboratory Report 5273, April 22, 1959

Figure 7 - Recovered payload, NASA Flight 1.03

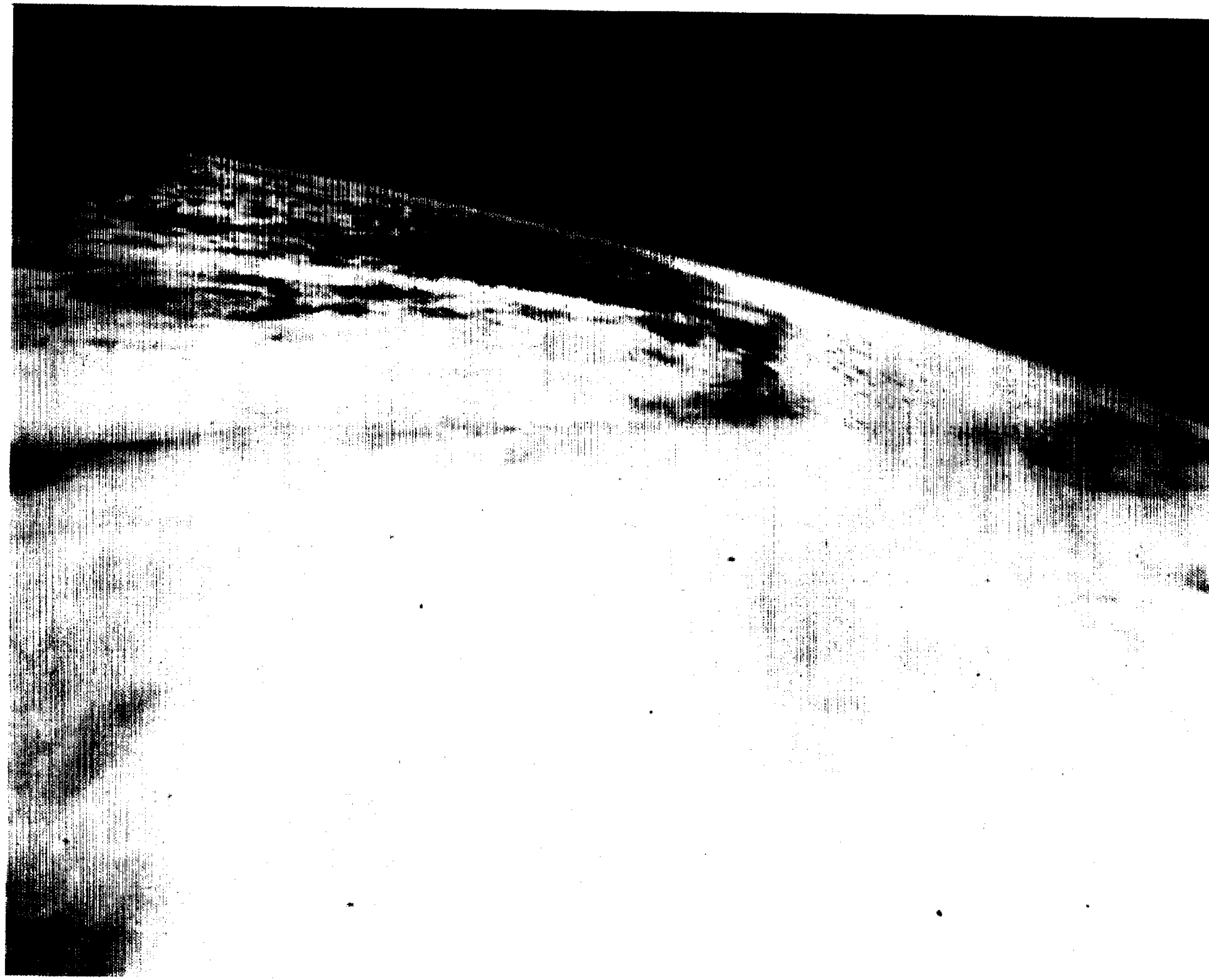

Figure 8 - NASA Flight 1.03, altitude 46 miles - color film

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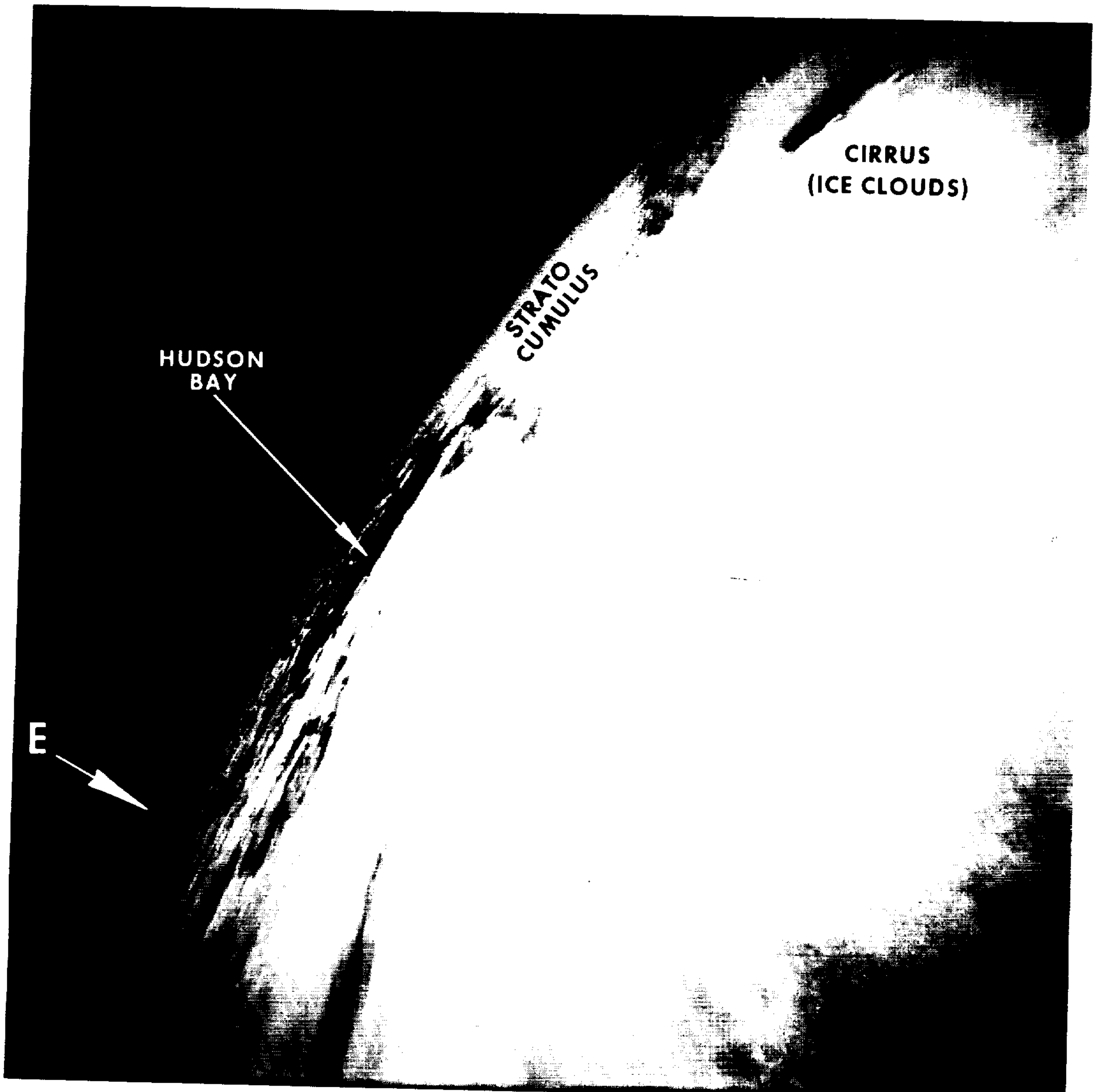

Figure 9 - NASA Flight 1.03, altitude approximately 45 miles - black-and-white film

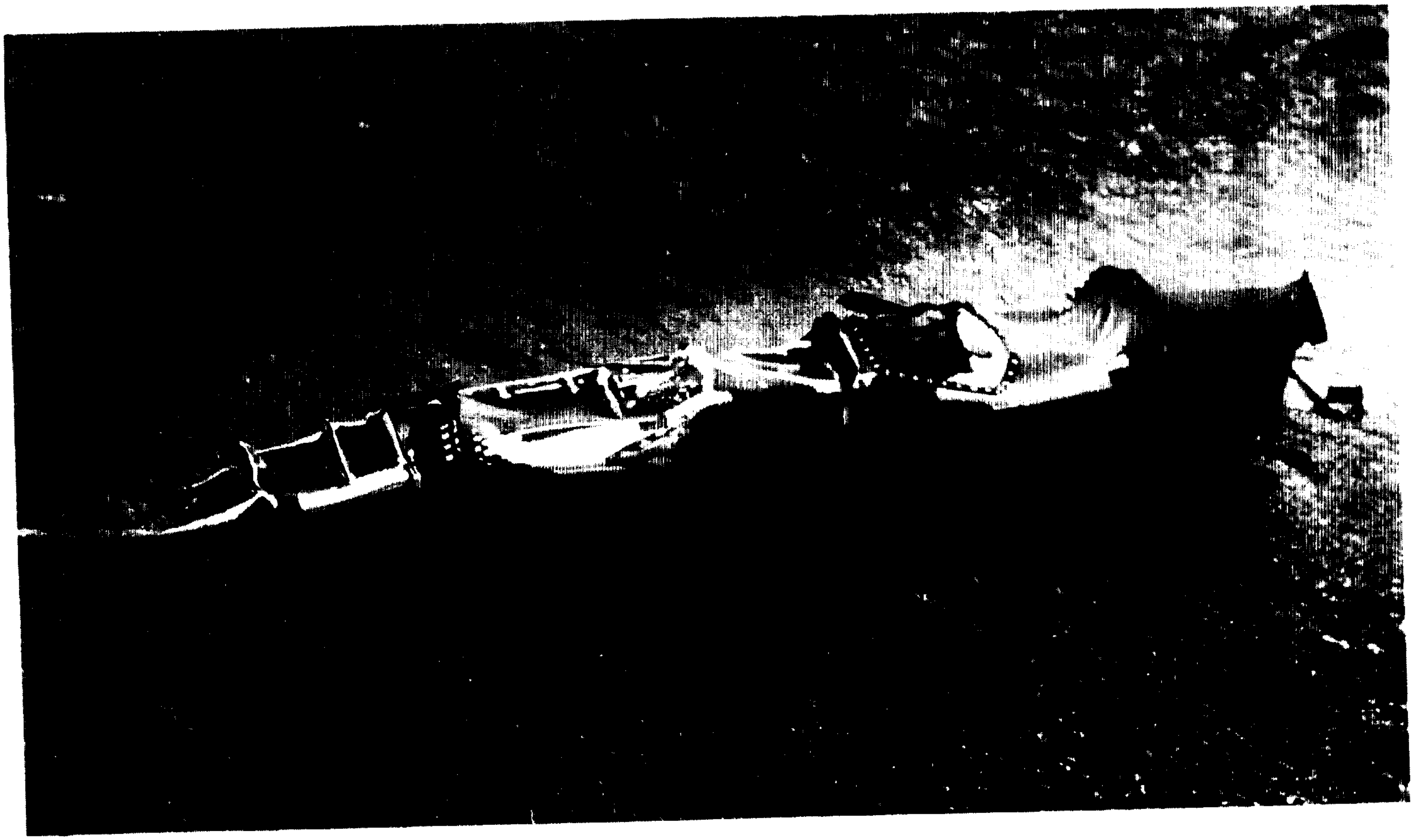

Figure 10 - Recovered payload, NASA Flight 1.05

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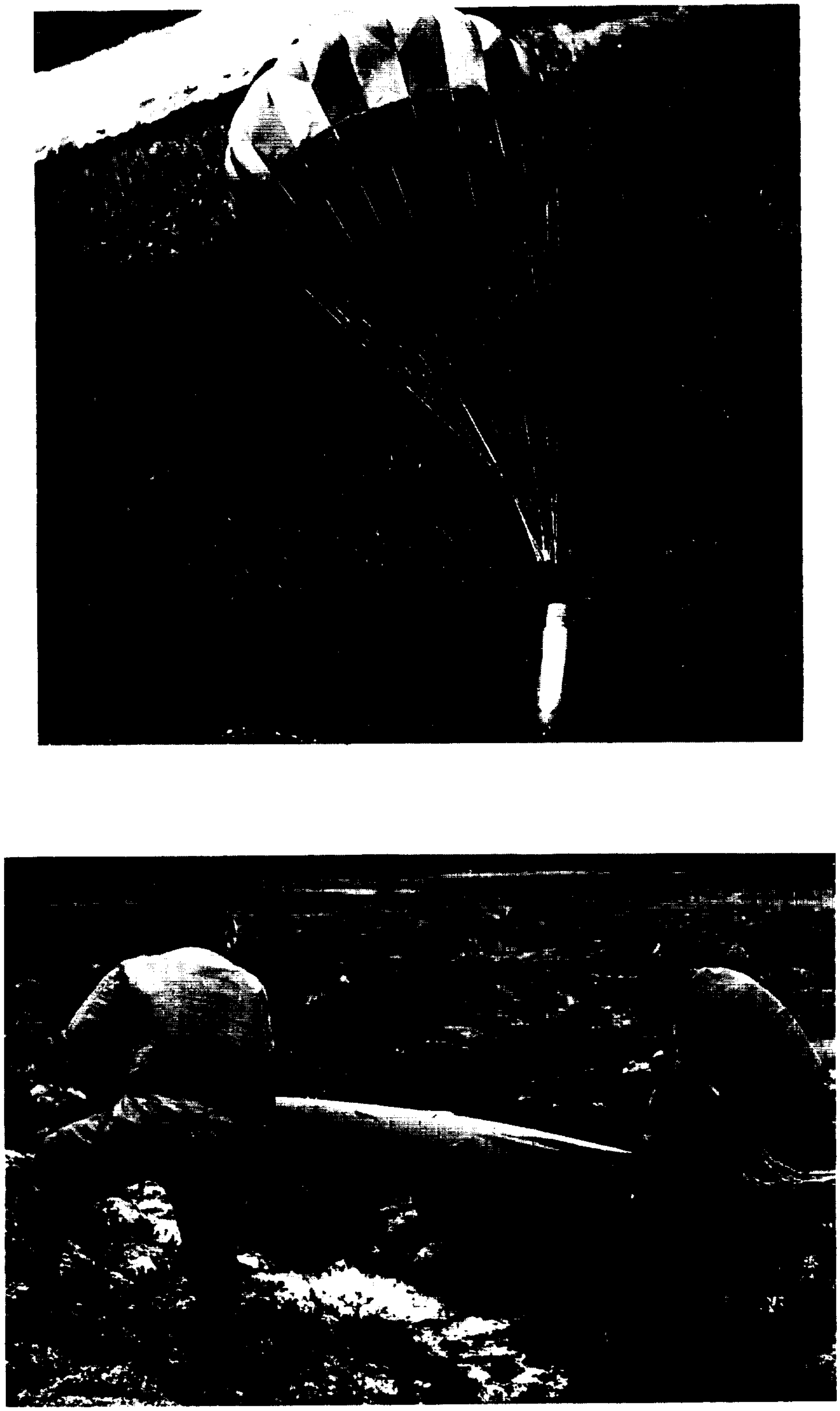

Figure 11 - Recovery of payload, NASA Flight 4.43

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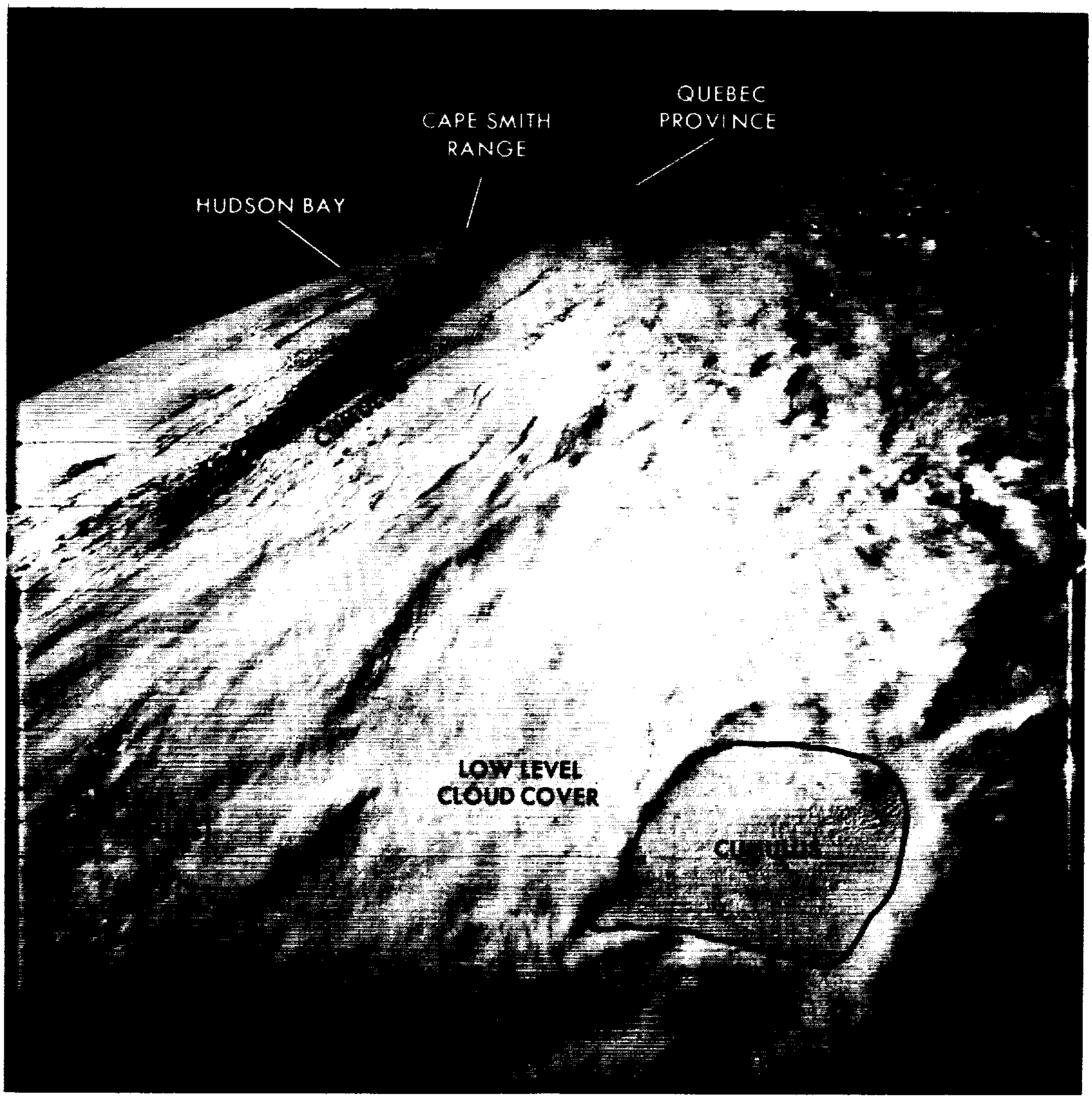

Figure 12 - NASA Flight 4.43, altitude 120 miles - black-and-white film

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Figure 13 - NASA Flight 4.43, altitude 109 miles - infrared film

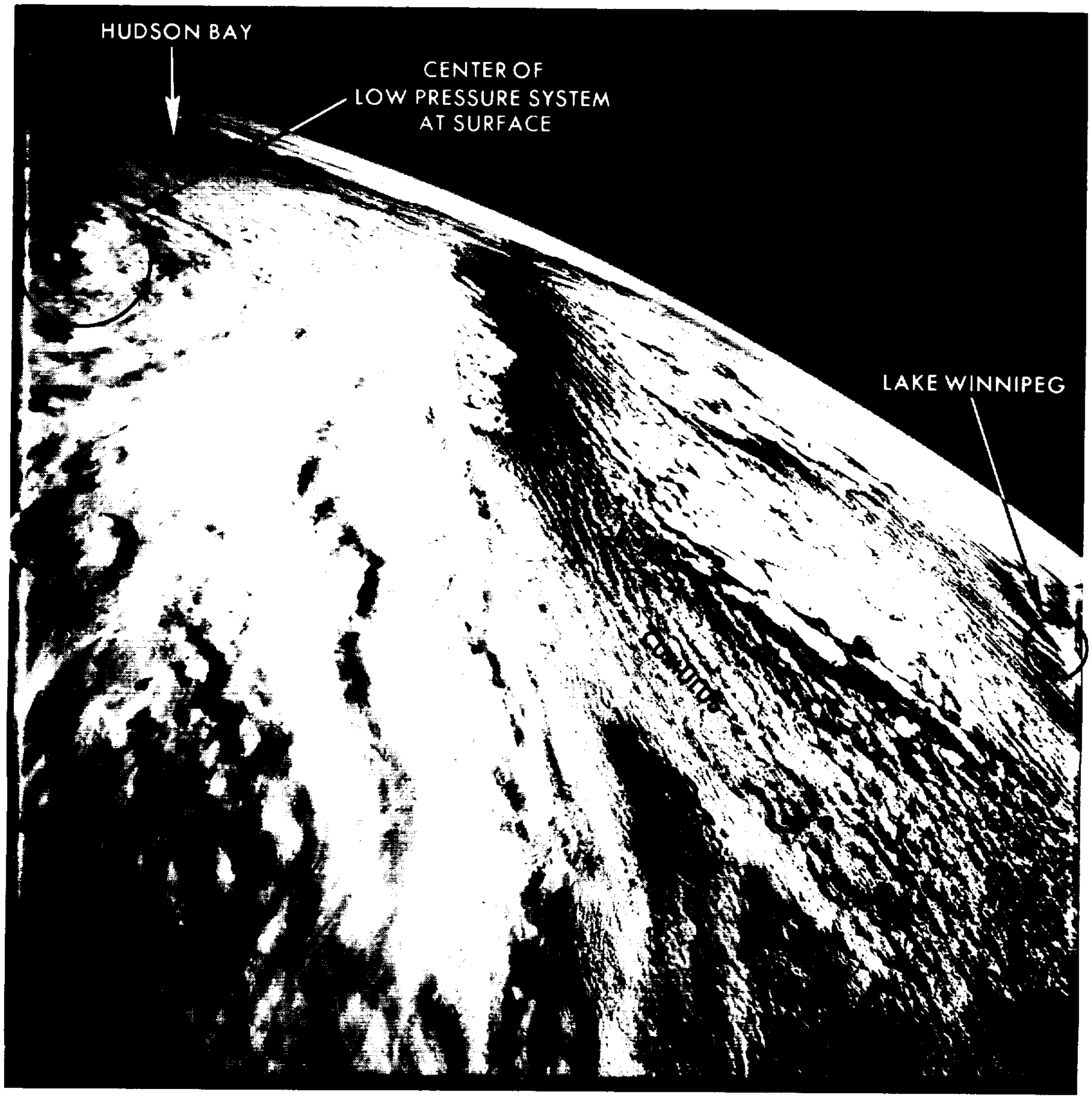

Figure 14 - NASA Flight 4.43, altitude 134 miles - black-and-white film

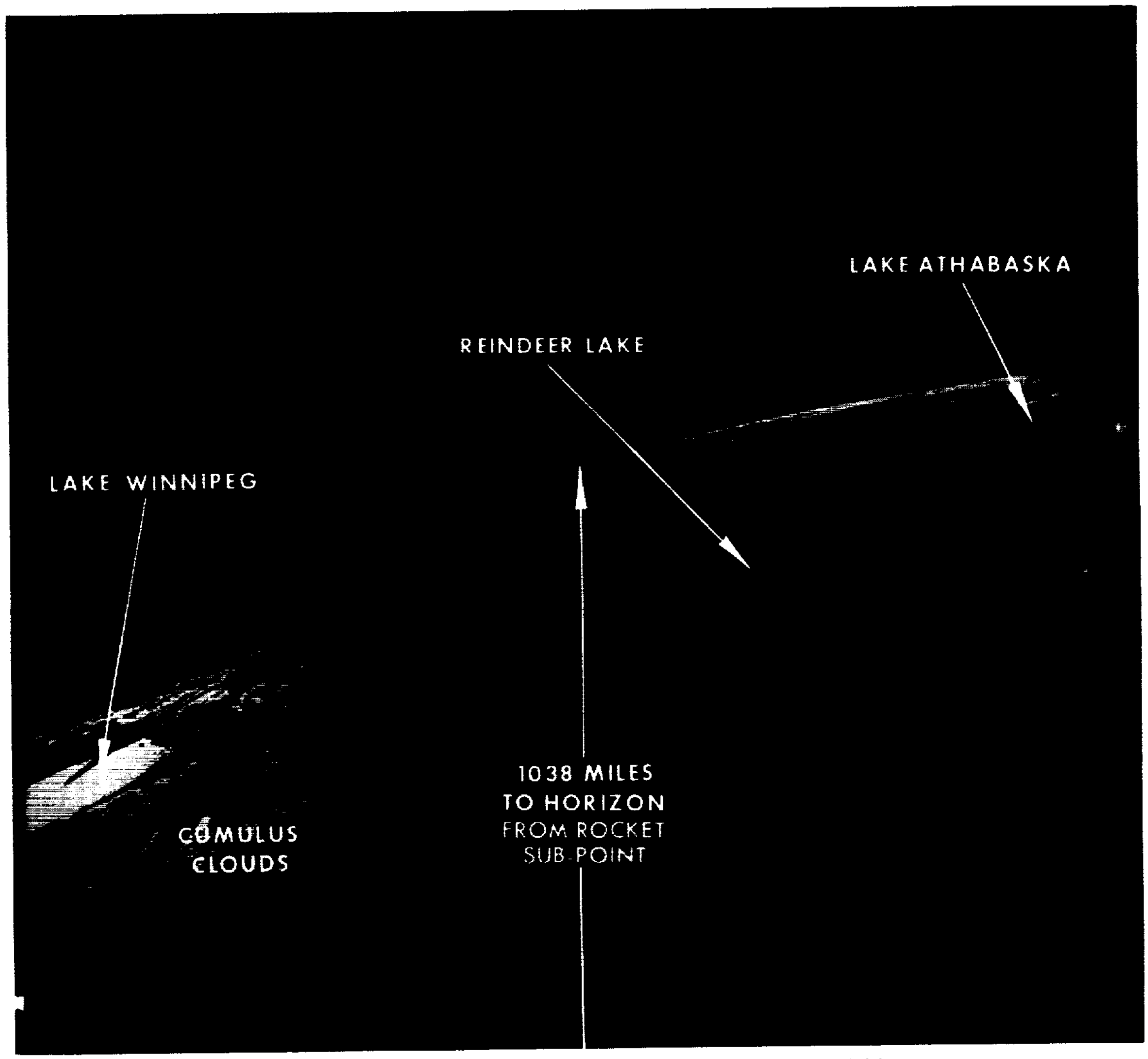

Figure 15 - NASA Flight 4.43, altitude 138 miles - infrared film. Lake Winnipeg appears white because of sun reflection.

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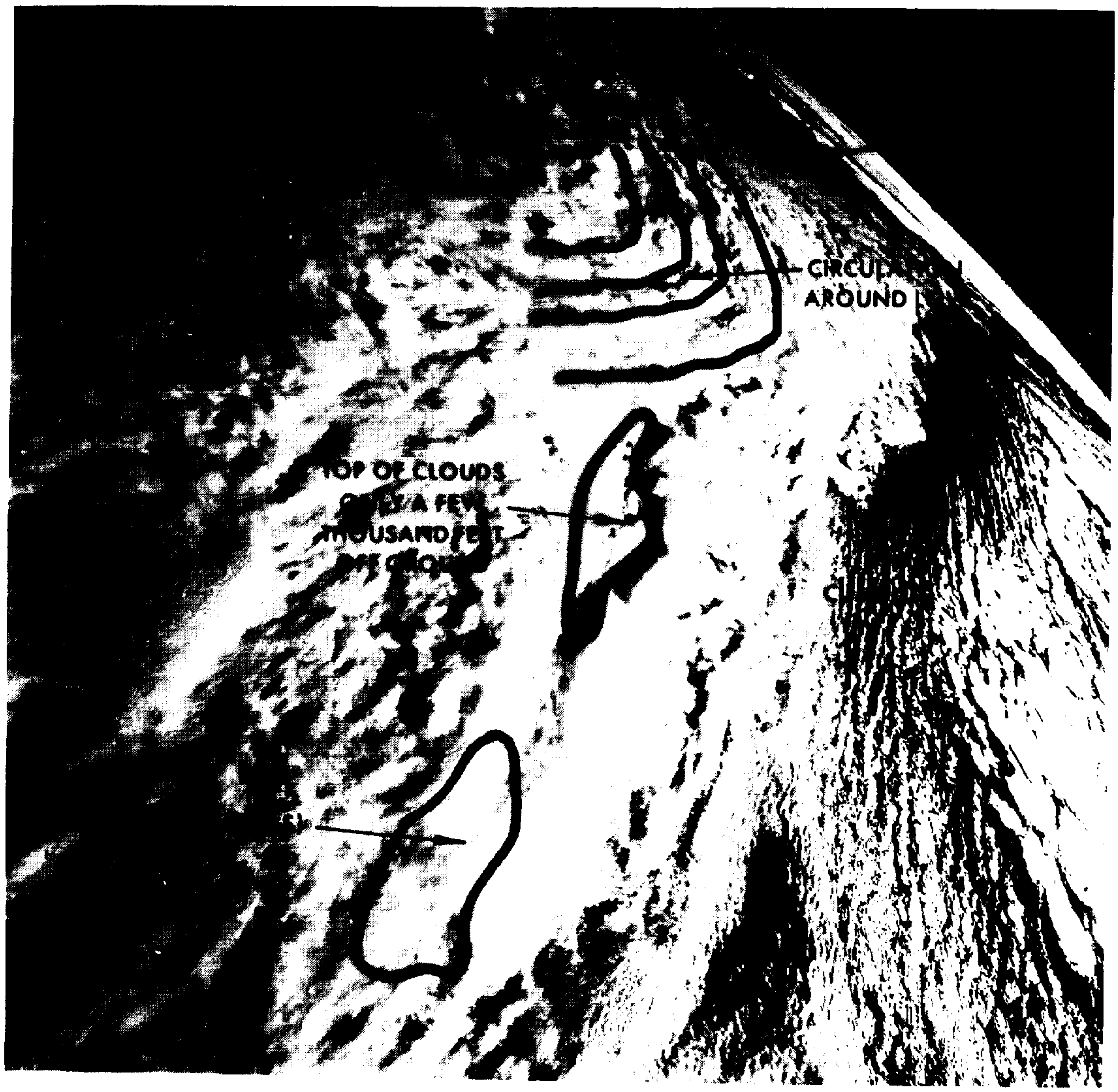

Figure 16 - NASA Flight 4.43, altitude 140 miles - infrared film

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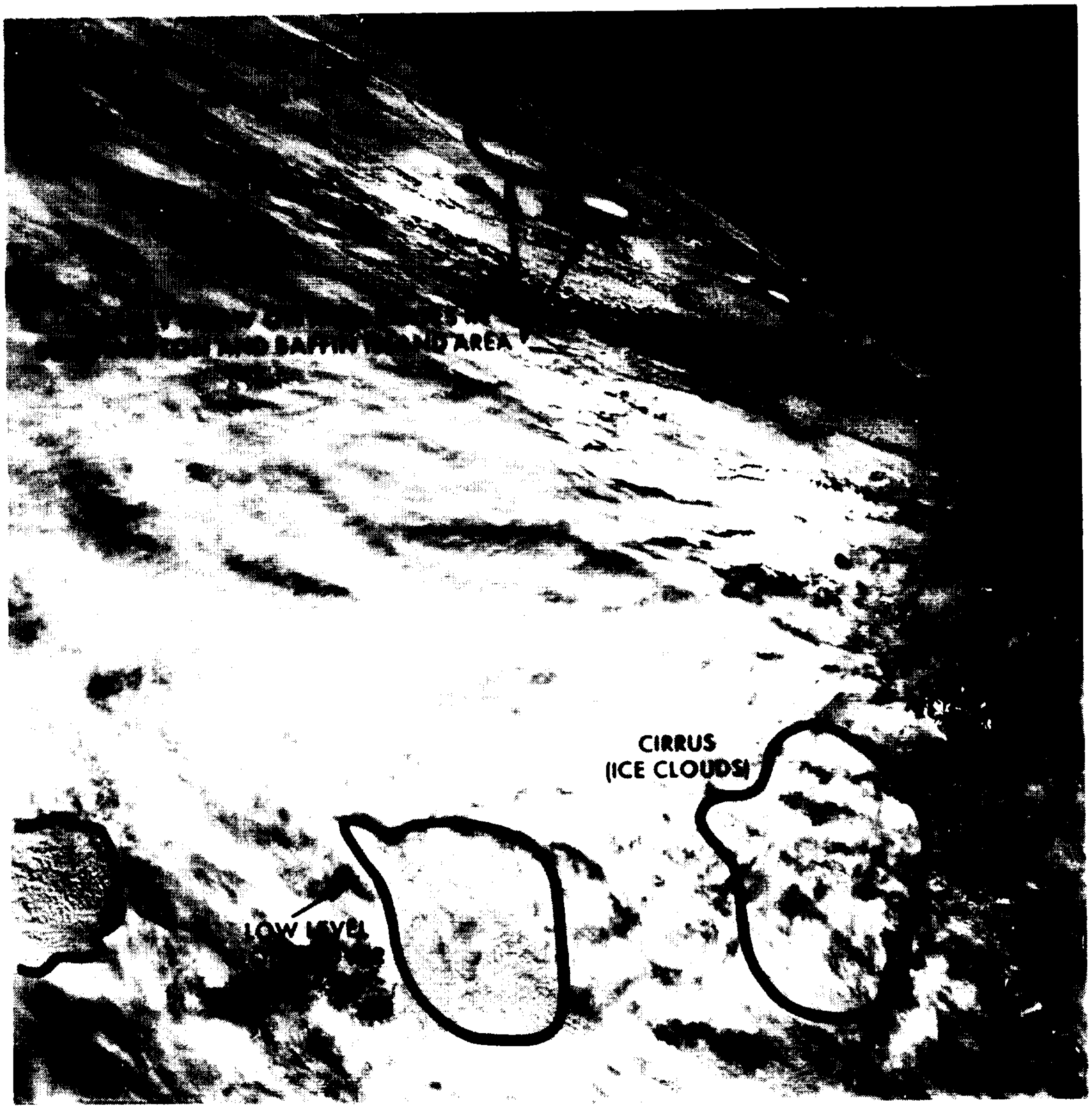

Figure 17 - NASA Flight 4.43, altitude 139 miles - infrared film

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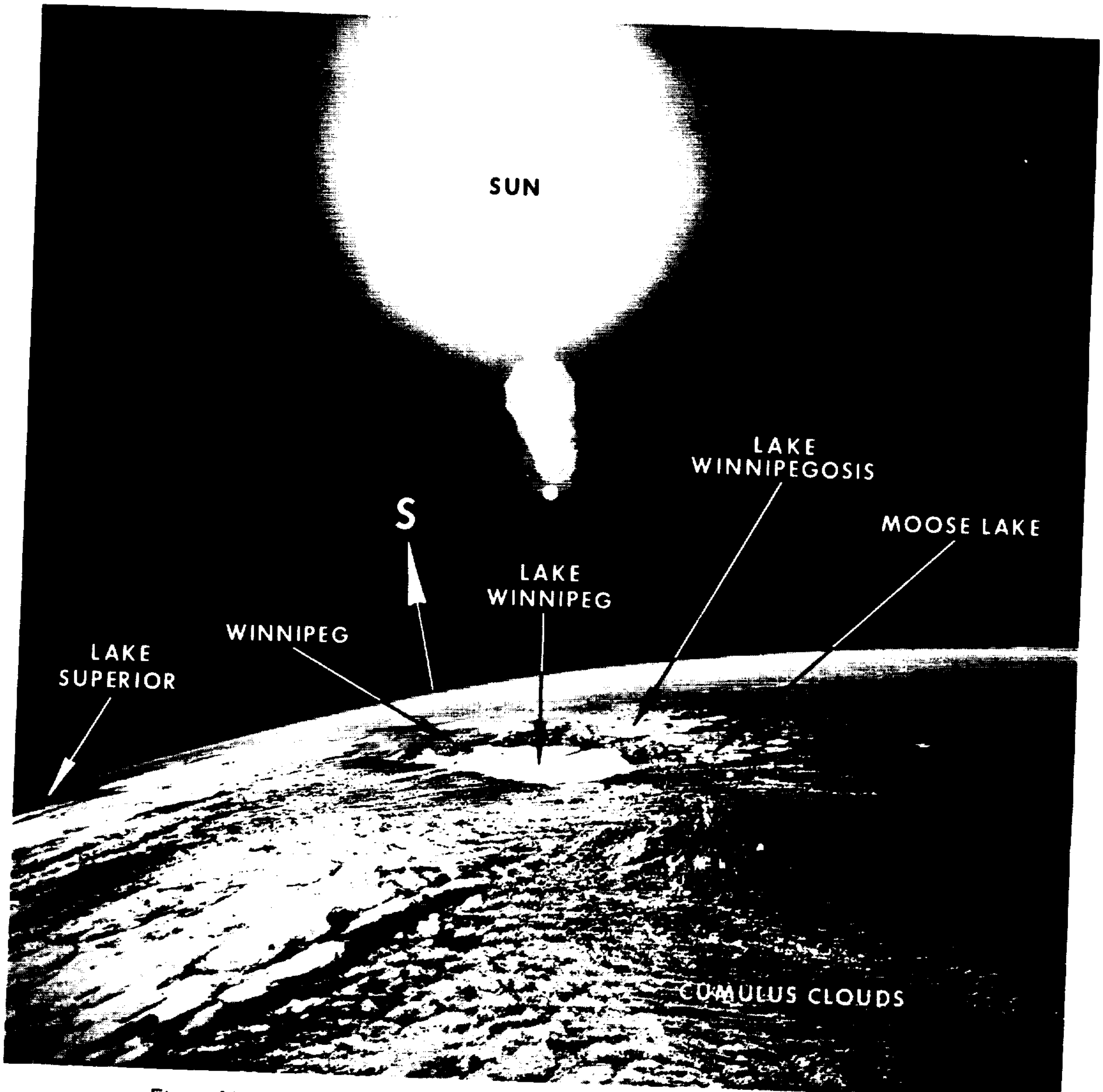

Figure 18 - NASA Flight 4.43, altitude 138 miles, looking south - infrared film.
Lakes appear white because of sun reflection.

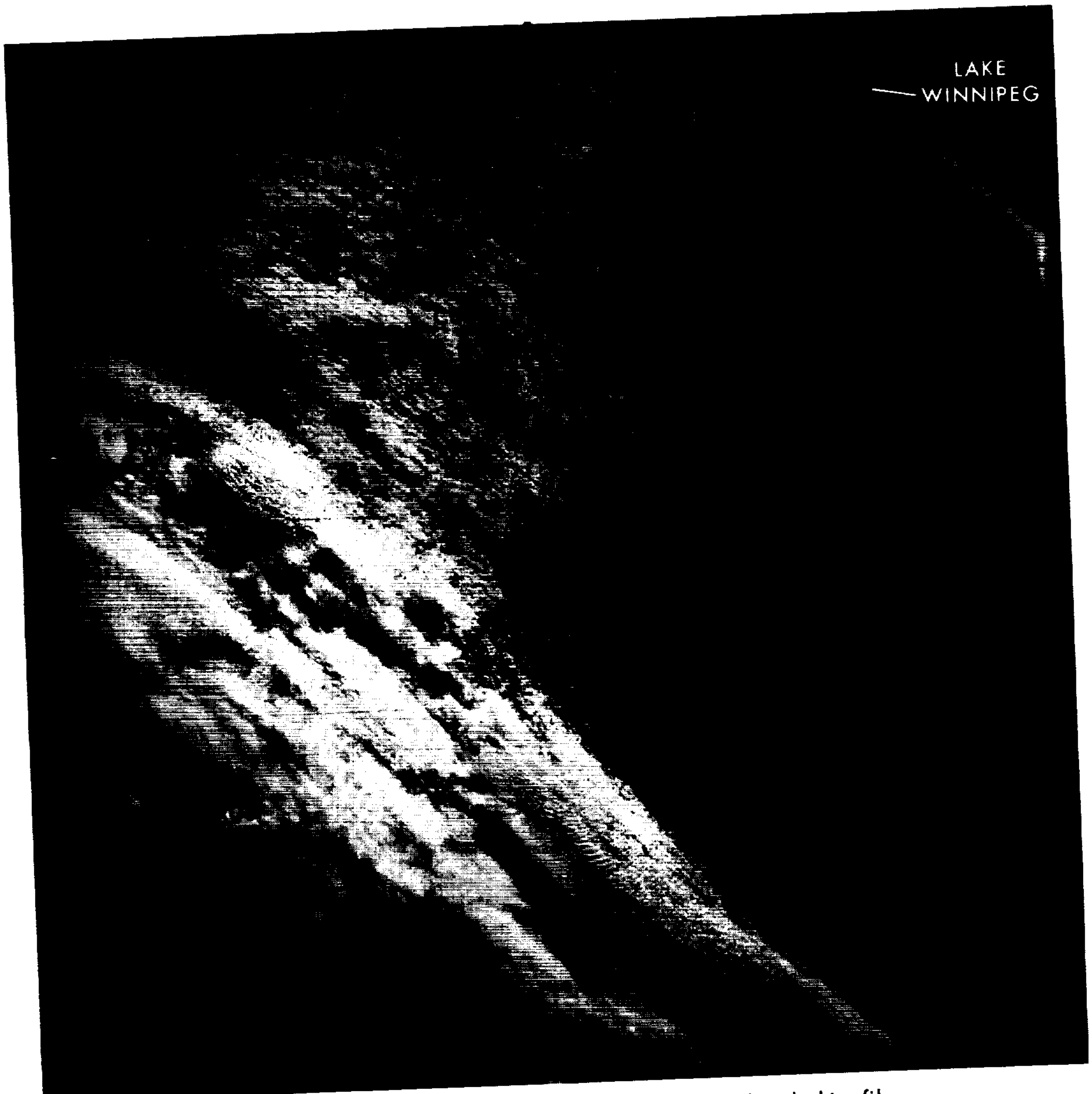

Figure 19 - NASA Flight 4.43, altitude 123 miles - black-and-white film.
Lakes appear white because of sun reflection.

D-706

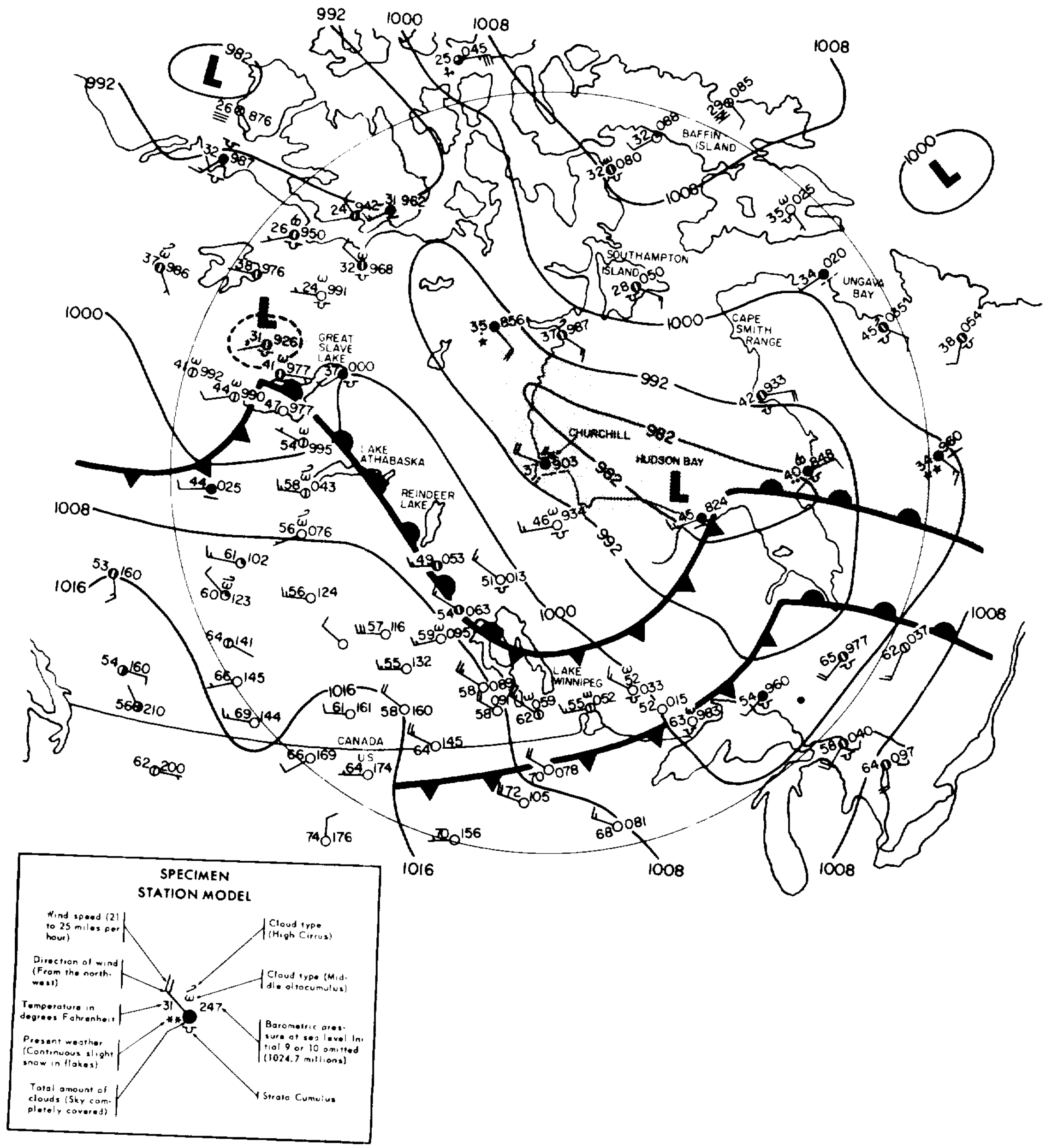

Figure 20 - Weather map of area covered by NASA Flight 4.43 photographs